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13. ABSTRACT (Maximum 200 words)

This work was funded as an augmentation for U.S. citizen graduate students to the George Mason University (GMU) C3I Center project "Multicasting Networks for Distributed Simulation" supported by the Defense Modeling and Simulation office (DMSO) under contract DCA100-91-C-0033 administered by the Defense Information Systems Agency. The basic premise of the DMSO-funded research area is that improved use of multicast networking technology will greatly enhance and reduce the implementation cost of distributed virtual simulation. This project has fulfilled the purpose for which the AASERT funding was provided: to attract qualified U.S. citizen students to develop expertise in, and continue with careers in defense-relevant areas. Evidence of this are one graduated doctoral student and two Master's students working in defense information technologies, one graduate student now in the Stanford doctoral program, and six ongoing students who will now be supported by other projects. In addition the project has supported good R&D work in network technology and military simulation, as evidenced by the papers listed above and the fact that two of its research prototypes have been adopted for industry projects and ultimately for use in the Department of Defense.

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**Final Technical Report**
**AASERT-Funded Graduate Student Work**
**Multicasting Networks for Distributed Simulation**

**Center of Excellence in Command, Control, Communications and Intelligence**
**George Mason University**
**J. Mark Pullen, Principal Investigator**
**30 June 2000**

## 1. Overall research area

This work was funded as an augmentation for U.S. citizen graduate students to the George Mason University (GMU) C3I Center project "Multicasting Networks for Distributed Simulation" supported by the Defense Modeling and Simulation office (DMSO) under contract DCA100-91-C-0033 administered by the Defense Information Systems Agency. The basic premise of the DMSO-funded research area is that improved use of multicast networking technology will greatly enhance and reduce the implementation cost of distributed virtual simulation. Multicasting is a technology whereby the network delivers each information packet to a whole group of computers, rather than just to one computer as is done in the much more common "unicast" form of networking.

### 1.1 Dual-Mode Multicast

Under this project, one student investigated applicability of Dual-Mode Multicast as an architecture for large-scale, wide-area distributed simulation. As proposed by the PI under the DMSO-sponsored project, Dual-Mode Multicast uses two different multicasting protocols: unlimited numbers of groups of Internet Protocol Multicast for the local area network, to organize flow of simulation state data to simulators; and one group of any available multicasting protocol in the wide-area network, to achieve efficient multi-site distribution of data, in a secure mode if necessary. Analysis of the costs and benefits associated with the Dual Mode Multicast architecture was pursued by an AASERT-funded student who prepared simulation software for Dual-Mode Multicast as an architecture for large-scale, wide-area distributed simulation, using planned exercise data provided by the DARPA Synthetic Theater of War (STOW) program office, and published his results.

### 1.2 Selectively Reliable Transport Protocol

The research area receiving the greatest attention under this project was the Selectively Reliable Transport Protocol (SRTP) for multicast distribution of distributed simulation data. In general, fully reliable delivery of multicast data in a real-time environment is not possible due to inherent constraints imposed by reliable delivery that are inconsistent with multicasting. However, Distributed Interactive Simulation requires certain information to be delivered in a reliable mode to some receivers under certain circumstances. The role of SRTP as proposed by the PI is to achieve the required

transmission efficiently in a multicast environment in a way that is transparent to the simulation application. In the first year of effort an AASERT-funded student formally defined the SRTP protocol, simulated its performance, created a prototype implementation, and published the results. This set the stage for four more years of productive effort that eventually led to a project with industry to implement SRTP in a project for the Defense Threat Reduction Agency (DTRA).

In the second year the same student expanded this prototype to a working implementation, documented its design in an Internet Draft (the initial document in the Internet Engineering Task Force protocols process), and along with another researcher in the lab used it to implement a light-weight Run-Time Infrastructure (RTI) for distributed virtual simulation under the High-Level Architecture (HLA) for modeling and simulation (see below). In the following year another student undertook performance analysis and refinement of SRTP. The results were published in the distributed simulation community and also were presented at the Internet Research Task Force Reliable Multicast Research Group. Those results indicated a need for improved congestion control in SRTP. Subsequently, one student developed a traffic generation model for a battlefield simulation using SRTP, while another undertook development of a revised implementation to make use of experimental congestion avoidance methods. The result of that work was a sufficiently robust and well-characterized version of SRTP to serve as the basis for a project with industry (Cubic Corp.) that will make the benefits of SRTP available to DTRA.

### 1.3 Networking Simulations with C4I Systems

A major potential benefit of multicasting is that it can enable improved performance in Command, Control, Communications, Computing and Intelligence (C4I) systems, either by themselves or linked to simulation systems. Under this project, two students investigated potential methods for supporting linked C4I and simulation systems with multicasting. They implemented of an experimental Distributed Interactive Simulation (DIS) protocol data unit (PDU) for network transmission of data between a Command Agent and a Semi-Automated Forces element. This work used the Disciple machine intelligence system, created by Dr. George Tecuci of GMU, coupled with the Modular Semi-Automated Forces (ModSAF) system funded by DARPA. Our C4I linkage technology ultimately was adopted by the government and used in an SAIC project under Naval R&D San Diego, supporting the Joint Warfighter Interoperability Demonstration (JWID) on two different occasions. Both of the students are now working in defense information technology companies.

### 1.4 Multicasting High Level Architecture (HLA) Run-Time Infrastructure (RTI)

After this project started, DMSO released the new HLA, which ultimately became a standard for DoD. The HLA requires an RTI middleware component to function. Our analysis showed that SRTP could provide enhanced network support for the RTI. To understand the requirements of the HLA better we created the Light-Weight RTI (LWRTI). Our initial prototype of LWRTI was developed by a French graduate student,

supported in our lab by the French Ministry of Defense under a program similar to AASERT, working with an AASERT-funded U.S. student who provided SRTP support. We learned a great deal about the HLA from that effort, but the prototype proved to have significant performance limitations as demonstrated when another AASERT-funded student completed a project to analyze and improve its performance, and published the results.

## 2. Students Supported

During the period of the project the Information Technology industry boom increased and our location in Northern Virginia became a global focal point of that boom. As a result it became progressively harder to attract and retain U.S. citizen students in graduate programs. Nevertheless, as described above, a great deal of effective research was accomplished, and eleven students have been supported at various levels. Four of these have graduated, with support from AASERT.

### 2.1 Doctoral Students

GMU has a unique interdisciplinary doctoral program, the PhD in Information Technology. Students Michael Hieb, MMMildred Ives, Dennis Moen and Nagesh Kakarlamudi from this program participated in the AASERT work. Michael Hieb graduated and is working for a defense information technology company. As it became harder to attract full-time doctoral students, the project employed several part-time doctoral students. Mildred Ives, Dennis Moen and Nagesh Kakarlamudi are part-time students who are employed with local information technology companies. Each of them has completed course work toward the PhD degree in cooperation with, and supported by, the AASERT project.

### 2.2 Master's Students

While it was originally envisioned that work on this project would be performed mostly by doctoral students, in fact a considerable portion of the work has been done by Master's students, either working in teams with doctoral students or working directly under supervision of the P.I. Students Roger Crutchfield, Kenneth Frosch, David Holland, Michael Ince, and Vincent Laviano fall into this category. Of these Frosch and Holland have graduated and are working for defense information technology companies in Northern Virginia. Laviano also has graduated and is now in the doctoral program in computer science at Stanford University.

### 2.3 Undergraduate Students

The role of undergraduate students in the project is to provide support in the laboratory. Nicholas Clark and Hung Nguyen have assisted with system administration and maintenance.

## 3. Research Products

### 3.1 Papers

The following papers have been published by the PI and students supported under AASERT:

Pullen, J. M. and V. Laviano, "Prototyping the Selectively Reliable Transport Protocol," Distributed Interactive Simulation Workshop, Orlando, FL, September 1995

Pullen, J.M. and V. Laviano, "Implementation of a Selectively Reliable Transport Protocol for DIS," Distributed Interactive Simulation Workshop, Orlando, FL, March 1996

White, E., V. Laviano, K. Frosch and J. M. Pullen, "Interfacing External Decision Processes to DIS Applications," Fifth Computer Generated Forces and Behavioral Representation Conference, Orlando, FL, July 1996

Hieb, M., G. Tecuci and J. M. Pullen, "Training a ModSAF Command Agent Through Demonstration ," Sixth Computer Generated Forces and Behavioral Representation Conference, Orlando, FL, July 1996

Pullen, J. M. and K. Frosch, "Design and Prototype of a Dual-Mode Multicast Application Gateway," Simulation Interoperability Workshop, Orlando, FL, September 1996

Laviano, V., "Selectively Reliable Multicast For Distributed Interactive Simulation," Master's Thesis, George Mason University, 1997

Frosch, K.and J. M. Pullen, "Design And Prototype Of A Dual-Mode Multicast Application Gateway," Simulation Interoperability Workshop, Orlando, FL, March 1997

Pullen, J. M. and M. Moreau, "Creating A Light-Weight RTI As An Evolution Of Dual-Mode Multicast Using Selectively Reliable Transmission," Simulation Interoperability Workshop, Orlando, FL, September 1997

Pullen, J. M. and V. Laviano, "Adding Congestion Control To The Selectively Reliable Transmission Protocol For Large-Scale Distributed Simulation," Simulation Interoperability Workshop, Orlando, FL, September 1997

Pullen, J. M. and N. Kakarlamudi, "Performance Issues for the Light-Weight RTI," IEEE Simulation Interoperability Workshop, Orlando, FL, September 1998

Pullen, J. M., "Reliable Multicast Network Transport for Distributed Virtual Simulation," *Proceedings of the Third International Workshop on Distributed Interactive Simulation and Real Time Applications*, IEEE, 1999

### 3.2 Prototypes

The SRTP prototype developed became the basis for ongoing work with Cubic Corp. in support of the distributed simulation environment at DTRA.

The C4I-ModSAF prototype developed became the basis for continuing work with SAIC in the MRCI that was later used in two military exercises, JWID'97 and JWID'98.

## 4. Summary

This project has fulfilled the purpose for which the AASERT funding was provided: to attract qualified U.S. citizen students to develop expertise in, and continue with careers in, defense-relevant areas. Evidence of this are one graduated doctoral student and two Master's students working in defense information technologies, one graduate student now in the Stanford doctoral program, and six ongoing students who will now be supported by other projects. In addition the project has supported good R&D work in network technology and military simulation, as evidenced by the papers listed above and the fact that two of its research prototypes have been adopted for industry projects and ultimately for use in the Department of Defense.